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TRAINING FOR A FLOATING-POINT DISPLAY OF NUMBERS

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Ames Research Center
Moffett Field, Calif.

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SUMMARY

An automatic typewriter was programmed for use in evaluating the response of subjects to floating- and fixed-point numbers. The task of receiving and returning numbers to a digital computer was simulated; that is, the subjects typed a fixed-point number on the machine or converted it to a floating-point number before typing it. Output was the reverse operation; that is, floating-point form was converted to fixed-point and fixed-point remained in fixed-point form. The results indicate that, under the conditions of the experiment, the high initial error rates in converting numbers decreased with training and became comparable to those made in simply repeating the fixed-point numbers. It is concluded that intensive training of inexperienced subjects on this "task element" is advantageous. The design of displays for digital computers which read out in floating-point form may not seriously affect performance if the subject is trained specifically for the task. The computer itself may be programmed to provide the initial practice and subsequent refresher exercises.

INTRODUCTION

Digital computing devices as integral parts of an airborne or space vehicle are not new. However, on-board digital computers which allow machine and man to interact are new, and may be necessary in future space vehicle systems. The list of functions which may be carried out by a digital computer is long: navigation and guidance, attitude control, star tracking, display activation and updating, system checkout and monitoring, storage of information vital to crew performance, etc. (ref. 1). Any computer on board a space vehicle must be lightweight, reliable, and small. Readout of numbers in fixed-point form requires more computer hardware than readout in floating-point form and thus compromises these aims. A greater number of significant figures may be represented in floating-point form for a given computer accuracy and complexity.

The interaction between man and computer is thus somewhat less direct with floating-point numbers because to comprehend their physical meaning, the operator must convert them to fixed-point or "conventional" form. For instance, if 200,000 feet were at some point in the mission a meaningful measure, its appearance in an 8-digit floating-point display with decimal fixed in the first cell is:

.2	0	0	0	0	0	0	0		+	6

where +6 is the power of 10 which must multiply the decimal number to yield 200,000. More simply, the decimal point is moved 6 places to the right. For values less than 1, the answer may not be seen completely on the display; for instance, the number,

.5	1	1	9	0	0	0	0		-	4

converted is 0.00005119 in fixed-point form.

However, probably more difficult than converting from floating-point to fixed-point form as above is converting from fixed- to floating-point form for input to the computer. There is a difference between carrying out the indicated operations as in the first case, and determining those operations in the second. For instance, the fixed-point number 1233.6704 becomes 0.12336704 times the appropriate power of 10 in floating-point form. To get the original number, the correct number of places to move the decimal (4 places) must be counted and a sign decided upon (+) for direction of movement. The final form then is

.1	2	3	3	6	7	0	4		+	4

Again, with numbers less than 1, 0.00079312 becomes,

.7	9	3	1	2	0	0	0		-	3

Because the floating-point form has to be converted, it was hypothesized that errors would probably be more numerous than for inputs to a computer which merely reproduced fixed-point numbers. The questions for this study were:

1. How much less accurate is performance utilizing floating-point numbers than fixed-point numbers?

2. Will training decrease this difference significantly?

3. Will procedural stresses (secondary task and speed stress) retard or even nullify the influence of training?

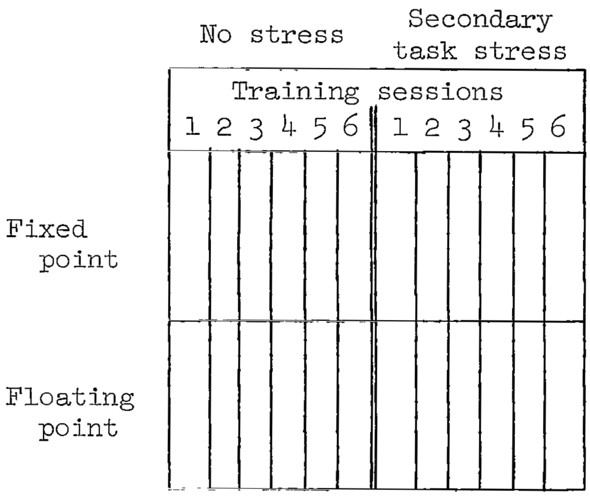
4. How much training is required?

The manual aspects of the task were not considered in this study. The input device, the typewriter keyboard, was unchanged throughout all conditions of the experiment. Nearly all of the subjects used a single finger to type numbers.

METHOD

Experimental Design

The different conditions under which the experimental subjects worked were no stress, secondary task stress, and speed stress. (The label "stress" does not imply a prejudgment of the effects on performance of the altered task structure in the latter two conditions.) The two kinds of display were floating-point and fixed-point numbers. Two factorial designs were used, each a 2x2x6 form, and a Lindquist Type VI analysis of variance was carried out for each (ref. 2).



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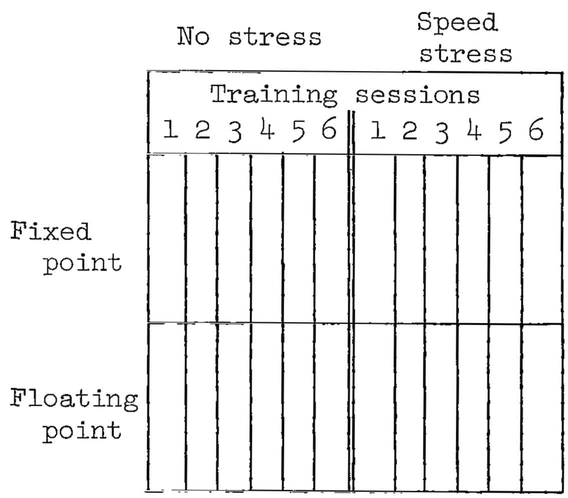

II

Each stress condition was imposed on 10 subjects. Since the scores of the 10 subjects under the "no stress" condition in design I were also used for the "no stress" condition of design II, only 30 subjects in all were used. Each of three groups of 10 were subjected to all training periods and both display modes. The only differences in treatment, then, were the stress conditions.

The subjects were chosen from men majoring in mathematics, engineering, and physical sciences at two nearby colleges and were assigned randomly to the conditions of the experiment. These people were chosen because they would not have to be trained on the meaning of decimal manipulation and a portion of their formal schooling was similar to that of astronauts.

Every subject completed six 1-hour sessions, each consisting of 100 trials. It was impossible to schedule the student subjects for regularly spaced intervals of training. It was possible, however, to adhere to the condition that the six sessions be completed within a two-week period. The subjects appeared to have high motivation and only 1 subject out of 31 failed to complete the six sessions, but this was due to circumstances beyond his control.

The learning curve appeared not to have reached an asymptote after six training sessions under the speed stress condition. Therefore, those subjects who had been in this group were asked to complete an additional four sessions, making ten in all.

Program Generation

The stimulus numbers were selected from tables of random numbers with appropriate permutations to vary the magnitude of the number. Numbers resulted which fell between 0.00000001 and 99999999. Half of these were used in fixed-point form and half were converted to floating-point form with exponents randomly determined and ranging from -8 to +8. They were then punched on paper tape to be fed to an automatic typewriter for the experimental trials. Four types of trials resulted, but the subject always started or ended each trial with a fixed-point number. That is, the complete set of input-output combinations is shown in the following paradigm, but only the first four of the eight possible combinations were used in the study, because it is assumed that the operator uses only fixed-point numbers.

Extracomputer form of number		Kind of computer display
Fixed point	IN → / ← OUT	Fixed point
Fixed point	IN → / ← OUT	Floating point
Floating point	IN → / ← OUT	Fixed point
Floating point	IN → / ← OUT	Floating point

The four types of trials which resulted were:

(a) Input a number into a fixed-point computer.

EXAMPLE:
Flexowriter types: 1234.5678 - FIXED -
Subject responds by typing 1234.5678

(b) Input a number into a floating-point computer.

EXAMPLE:
Flexowriter types: 1234.5678 - FLOATING -
Subject responds by typing .12345678 + 4

(c) Receive a number from a fixed-point computer.

EXAMPLE:
Flexowriter types: 1234.5678
Subject responds by typing 1234.5678

(d) Receive a number from a floating-point computer.

EXAMPLE:
Flexowriter types: .12345678 + 4
Subject responds by typing 1234.5678

Each of these four types of trials occurred 25 percent of the time in each session. Their order of appearance was randomly determined, trial by trial, for each program.

One training session was 1 hour long and consisted of 100 numbers. Six punched paper tapes were prepared for use in programming the numbers for the first six sessions. Later, four more were prepared in order to extend training under the speed stress condition. All subjects in all conditions responded to the numbers on the first six program tapes.

A "comfortable" response time was provided for the subjects under all conditions. Under the speed stress condition, however, the stimulus presentation interval was shortened by masking the number which had been typed by the Flexowriter. The amount to shorten this time interval was determined from an analysis of response time records of the subjects under the first two conditions (no speed stress). The amount of time used by each subject in typing his answer to each problem was determined from oscillograph records. These time values were then separated into four groups, each containing the time scores for all subjects on one of the four types of problems described above. The mean and standard deviation for each of the four types of problems were computed, and it was then determined that the means and standard deviations for three of the types were of nearly the same value. These three types included both of those requiring retyping of a fixed-point number (types a and c), and the type requiring conversion of a number from floating- to fixed-point form (type d). The mean response time for the type of problem requiring conversion from fixed- to floating-point form, however, was considerably higher than the mean values of the other three types. To impose relatively the same amount of speed stress on each group, the stimulus presentation time was reduced to a value one-half a standard deviation below the mean for each group. This resulted in two stimulus presentation intervals; one interval of 5.2 seconds for the three groups with mean values nearly equal (types a, c, and d), and one interval of 7.4 seconds for the group requiring conversion from fixed to floating point (type b).

Instrumentation

A Friden Flexowriter, Model SPD, with remote tape punch and reader, Models ATP and ATR, respectively, was the central piece of equipment in the study. The Flexowriter was programmed to type numbers, to provide a time interval for the subject's response, and to record the subject's response adjacent to the correct response on punched tape. The response tape was then fed back to the Flexowriter and the correct responses, as well as the subject's responses, were automatically typed out and then "hand scored."

A sufficiently long response interval (25 seconds) was programmed into the tapes to allow the subjects to type their responses unhurriedly. This was done so as not to confound the nonmotor aspects of the task with the motor aspects, the former being the main object of study.

In providing the speed stress, one of the procedural stresses of concern, a masking mechanism was attached to the carriage of the typewriter. The tape was programmed to provide a pulse to a solenoid on the mask to allow the mask to drop down and conceal the stimulus number, after the predetermined period of time for stimulus presentation had elapsed. The same response interval was again provided the subject; however, now he had either to operate on the number without delay before it disappeared behind the mask or to remember the entire number or the portion he had not completed at the time the mask covered the stimulus.

Response time was recorded by picking-off pulses resulting from key depressions on the typewriter keyboard. The pulses were fed to a Brush, BI-202, oscillographic recorder where pen deflections, both those initiated by the Flexowriter and by the subject, were recorded. Because of the regular appearance of the machine print-out and the randomly spaced subject responses, it was easy to establish a base and to measure the subject's response time. These measures were not used as a criterion variable but were used only as the basis for the choice of the stimulus presentation time for the speed stress condition discussed above.

The secondary task was provided by mounting 36 internally lighted push buttons on a slanted panel. One of the lights was randomly programmed to come on and remain on until the subject found a push button which would turn it off. The association between the light and the push button which turned it off was randomly determined for each experimental session. When the subject found the correct push button, the apparatus cycled to the next light in the series after a two-second time delay. The subject was required to write the number of the light which came on and the number of the push button he had depressed to turn the light off.

Figure 1 is a photograph of the experimental apparatus. The Flexowriter was connected to a remote punch and reader in the adjoining experimenter's room. Communication was by an office intercommunication system.

Experimental Procedure

Since a measure of response time was required to structure the speed stress condition, the experiment was run in two parts. The two conditions, no stress and secondary task stress, were run first to provide the measure of response time. Subjects were assigned at random to these two conditions.

When the subjects arrived they were given an explanation of the study and what they would be required to do. The subjects then tried the task and exercised with a one-half hour "training" tape. The experimenter assisted until the subject was thoroughly oriented to the requirements of the task. Then, at this initial session, the subject was given his first 1-hour tape. The subject was given no further indoctrination unless it was obvious that he was making errors because of having misunderstood some aspect of the task.

To prevent the subject from merely copying the results of his first cycle on the secondary task, he placed his paper in a receptacle when he had written down the 36 light and push-button associations. When the apparatus had cycled through the 36 steps, it returned to the first step again to cycle through in the same sequence.

The subjects in the secondary task condition were told that accuracy was of greater importance in the primary task than in the secondary task. The secondary task, while necessitating a shift in cognitive activities, did not seem to intrude upon the intervals of primary activity. Generally, the secondary task was worked on during the intertrial interval.

All subjects were told that accuracy was more important than speed and that although their response time would be recorded, it would not be used as a score. The only score used was the number of errors in number reproduction.

A correct response was one in which the number was typed perfectly. There were several kinds of errors: omission of numbers, transposition of numbers, wrong numbers, wrong sign for exponent, wrong exponent, etc. Though two or more of these errors might occur on any one trial, they were scored as a single error. Thus each trial was either right or wrong.

RESULTS AND DISCUSSION

Figure 2 shows the mean number of errors of 10 subjects for each of the training sessions on floating-point numbers (types b and d) and on fixed-point numbers (types a and c). This is the performance when no stress was imposed. Figure 3 is a plot of 10 other subjects who were given the secondary task stress.

It is obvious that there is a diminution of errors as training progresses. Even fixed-point performance, which required that the subject merely copy numbers by typing them into the Flexowriter, shows some improvement. Never is floating-point performance better than fixed-point performance; however, floating-point performance (which required a conversion of the number from or to floating-point before typing it into the Flexowriter) does ultimately equal or exceed the beginning fixed-point performance.

A measure of the precision of the experiment is shown in the analysis of variance values in table I. The display mode, sessions, and mode-sessions interactions are all significant. These mean simply that the effects illustrated in the figures are not due to chance, namely:

Display mode: There was a difference in performance on the floating- and fixed-point modes.

Sessions: Training did affect performance.

Mode X sessions: Training affected floating-point performance more than it did fixed-point performance.

Condition: There was no difference between scores for the group performing under no stress and those performing under the secondary task condition.

It appeared that the secondary task imposed little stress. Though the secondary task required a shift in attention, the subjects seemed to be able to "sandwich" it in between trials on the numbers and to sacrifice it to consideration of the primary task when necessary.

Figure 4 shows the mean number of errors of the 10 subjects for each of the training sessions on floating- and fixed-point numbers. This is the speed stress group. Since six sessions seemed insufficient for fully training the subjects, they were asked to return for an additional four sessions.

Again, training was very effective in reducing errors on both display modes. The performance improvement under the speed condition is more dramatic, but takes a little longer to reach a stable level of excellence. An interesting phenomenon in the floating-point curve is the apparent "plateau" occurring over sessions 5, 6, and 7 and then the subsequent "jump" to better performance levels over sessions 8, 9, and 10. This suggests that a qualitative change in response occurred which may be similar to the sudden increase in typing speed which occurs when the typist advances from typing word fragments to typing whole words.

The speed stress condition was compared with the no stress condition and the analysis of variance is shown in table II. All the differences noted are significant beyond the 0.05 level. Now, however, there is a difference between groups (conditions) as indicated by the condition and interaction terms. These are:

Condition: The group under the speed stress did not perform as well (over six sessions) as the group under no stress.

Display mode X condition: The relationship between fixed- and floating-point performance under no stress is changed under the speed stress condition. Under the former, fixed-point performance is relatively stable; however, under the latter it initially deteriorated along with floating-point performance. The nature of the performance difference thus has changed.

Session X condition: Training had a greater effect under the speed stress condition.

Display mode X session X condition: Training affected floating-point performance more than it did fixed-point performance under the no stress condition. This effect was not apparent under the speed stress condition.

The above remarks and the analysis refer only to the first six training sessions under the speed stress condition.

An estimate was made of the significance of the differences between floating- and fixed-point performance at each training session under all three conditions. Accordingly, using methods outlined by Lindquist (ref. 2, pp. 91-93), tests were applied to these differences via the method of finding a "critical difference." The critical difference was 2.5. It can be seen from figures 2, 3, and 4 that:

Under the no stress condition (fig. 2) the differences in performance on floating- and fixed-point numbers are significant for the first three sessions and are insignificant for the last three sessions.

Under the secondary task stress condition (fig. 3) the first three performance differences are significant, the fourth is not, the fifth is significant, and the sixth is not.

Under the speed stress condition (fig. 4) all of the performance differences remain significant until sessions 9 and 10. Extrapolating the analysis to these last two sessions, it would appear that they had become insignificant.

CONCLUDING REMARKS

The results of this study may be summed up in the following statements:

1. In a sample of college men majoring in mathematical, engineering, and scientific fields, a significantly greater number of errors were made initially in manipulating floating- than fixed-point numbers.

2. After six 1-hour automated practice sessions this difference was reduced to insignificance. When a speed stress was added, 10 sessions were required to reduce the difference to a similar degree.

3. With practice, performance on floating-point numbers can equal or exceed <u>initial</u> fixed-point performance.

4. Floating-point performance never exceeded fixed-point performance at any given level of training.

Subject interest and motivation seemed high and the authors' experience with the training device warrants their opinion that a task which would have been drudgery with paper and pencil as training media had been converted to one which fostered enthusiasm.

Although errors on floating-point performance decreased, fixed-point performance was always best and, where possible, numbers probably should be displayed in this form. However, this study suggests that users of digital computers which display numbers in floating-point form would benefit from a short, intensive training period of the kind suggested here. Setting up the equipment and training programs is quite economical and can be done wherever an automatic typewriter is available. The concept extends, of course, to the programming of the computer itself for automatic stimulus presentation, response recording, and score readout. It also extends to other subject matters that are amenable to programmed presentation. In such cases, where the material may be stored in the memory of the on-board computer in space vehicles, refresher training may be available on command of the astronaut. For extended space missions, this would seem to be mandatory for space-crew skill updating and desirable as a means for the alleviation of boredom.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Oct. 6, 1964

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2. Lindquist, E. F.: Design and Analysis of Experiments in Psychology and Education. Houghton Mifflin Company, Boston, 1956.

TABLE I.- ANALYSIS OF VARIANCE FOR "NO STRESS" VERSUS "SECONDARY TASK STRESS" CONDITIONS

Source	Degrees of freedom	Sum of squares	Mean square	Error source	F ratio	Significance
Between subjects	cn-1=(19)	1372.58	72.24		0.96	
Condition	c-1=(1)	69.34	69.34	e_b		None
Error(b)	c(n-1)=(18)	1303.25	72.40			
Within subjects	cn(ab-1)=(220)	3663.58				
Display mode	a-1=(1)	788.44	788.44	e_1	76.19	$P < (0.001)$
Sessions	b-1=(5)	1009.04	201.81	e_2	25.54	$P < (0.001)$
Display mode X sessions	(a-1)(b-1)=(5)	393.84	78.77	e_3	13.51	$P < (0.001)$
Display mode X condition	(a-1)(c-1)=(1)	3.04	3.04	e_1	.29	None
Sessions X condition	(b-1)(c-1)=(5)	21.74	4.35	e_2	.55	None
Display mode X sessions X condition	(a-1)(b-1)(c-1)=(5)	11.24	2.25	e_3	.39	None
Error(w)	c(ab-1)(n-1)=(198)	1436.26				
$Error_1(w)$	(a-1)(n-1)c=(18)	186.27	10.35			
$Error_2(w)$	(b-1)(n-1)c=(90)	711.31	7.90			
$Error_3(w)$	(a-1)(b-1)(n-1)c=(90)	538.68	5.99			

Display mode: Fixed or floating point, a = 2
Sessions: Training sessions, b = 6
Condition: Stress or no stress, c = 2
Number of subjects, n = 10
Total number of subjects, N = 20

TABLE II.- ANALYSIS OF VARIANCE FOR "NO STRESS" VERSUS "SPEED STRESS" CONDITIONS

Source	Degrees of freedom	Sum of squares	Mean square	Error source	F ratio	Significance
Between subjects	cn-1=(19)	8378.73	440.99			
Condition	c-1=(1)	5339.27	5339.27	e_b	31.62	P < (0.001)
Error(b)	c(n-1)=(18)	3039.47	168.86			
Within subjects	cn(ab-1)=(220)	10105.00				
Display mode	a-1=(1)	1685.40	1685.40	e_1	167.04	P < (0.001)
Sessions	b-1=(5)	4387.58	877.52	e_2	67.04	P < (0.001)
Display mode X sessions	(a-1)(b-1)=(5)	180.15	36.03	e_3	4.43	P < (0.005)
Display mode X condition	(a-1)(c-1)=(1)	216.60	216.60	e_1	21.47	P < (0.001)
Sessions X condition	(b-1)(c-1)=(5)	1419.38	283.88	e_2	21.69	P < (0.001)
Display mode X session X condition	(a-1)(b-1)(c-1)=(5)	124.15	24.83	e_3	3.05	P < (0.025)
Error(w)	c(ab-1)(n-1)=(198)	2091.73	10.56			
Error_1(w)	(a-1)(n-1)c=(18)	181.67	10.09			
Error_2(w)	(b-1)(n-1)c=(90)	1178.03	13.09			
Error_3(w)	(a-1)(b-1)(n-1)c=(90)	732.03	8.13			

Display mode: Fixed or floating point, a = 2
Sessions: Training sessions, b = 6
Condition: Stress or no stress, c = 2
Number of subjects, n = 10
Total number of subjects, N = 20

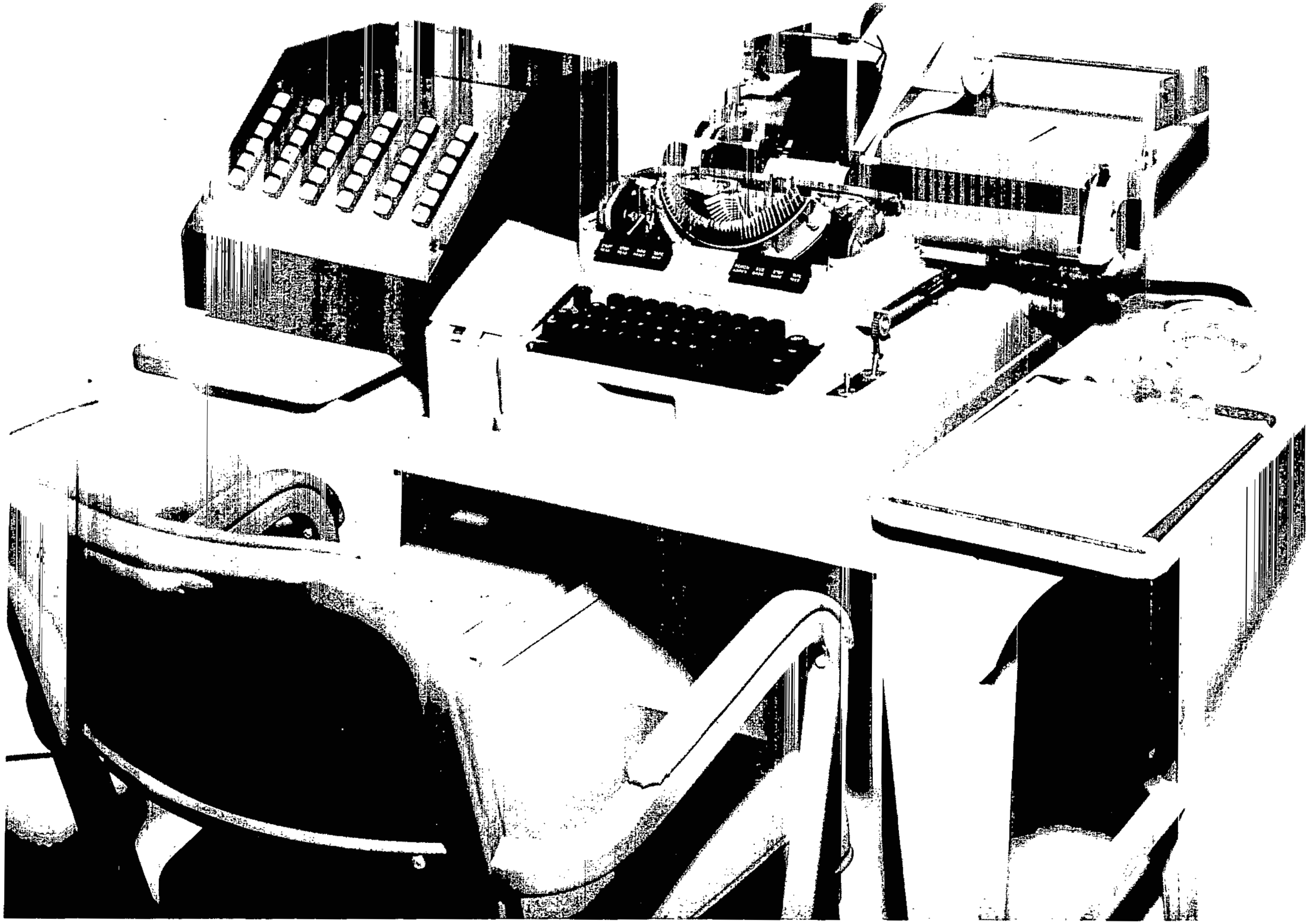

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Figure 1.- Subject's position showing automatic typewriter and secondary task panel.

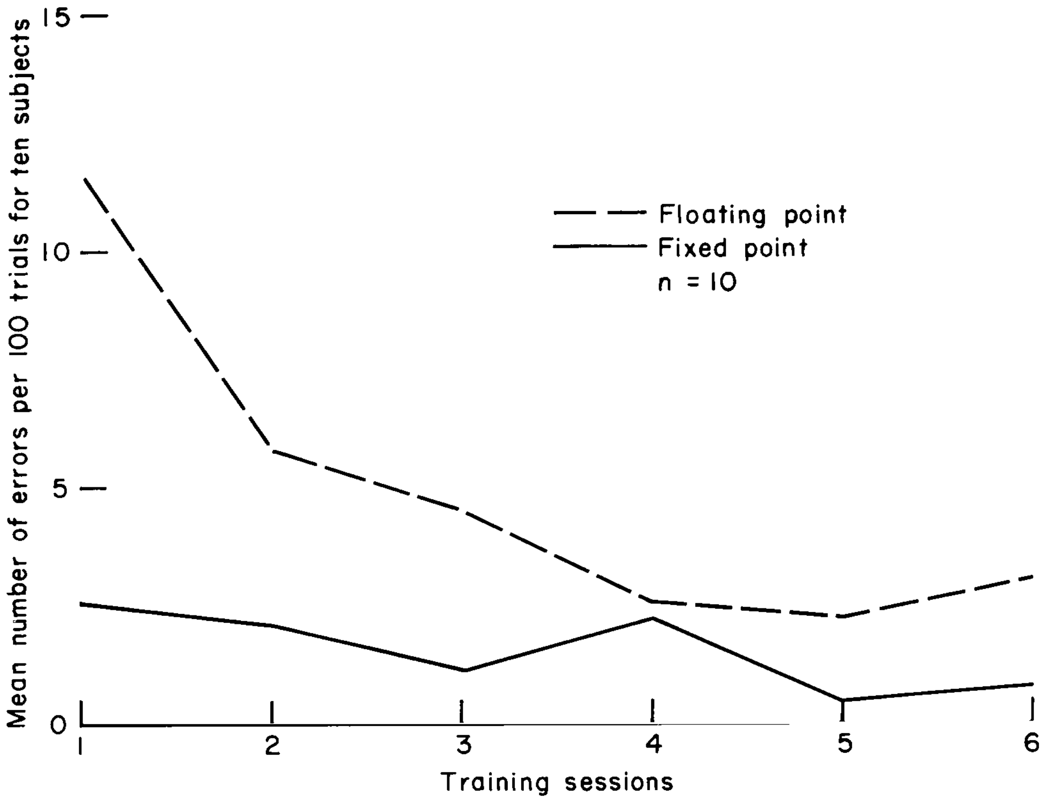

Figure 2.- Performance under "no stress" condition.

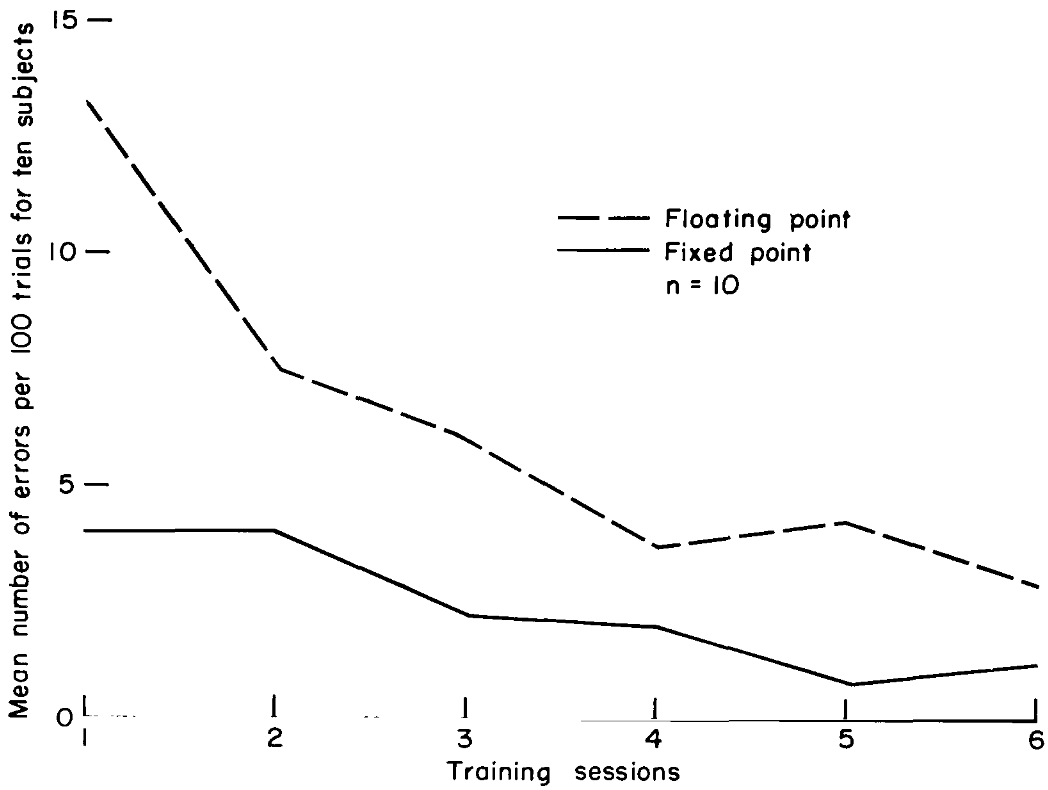

Figure 3.- Performance under "secondary task stress" condition.

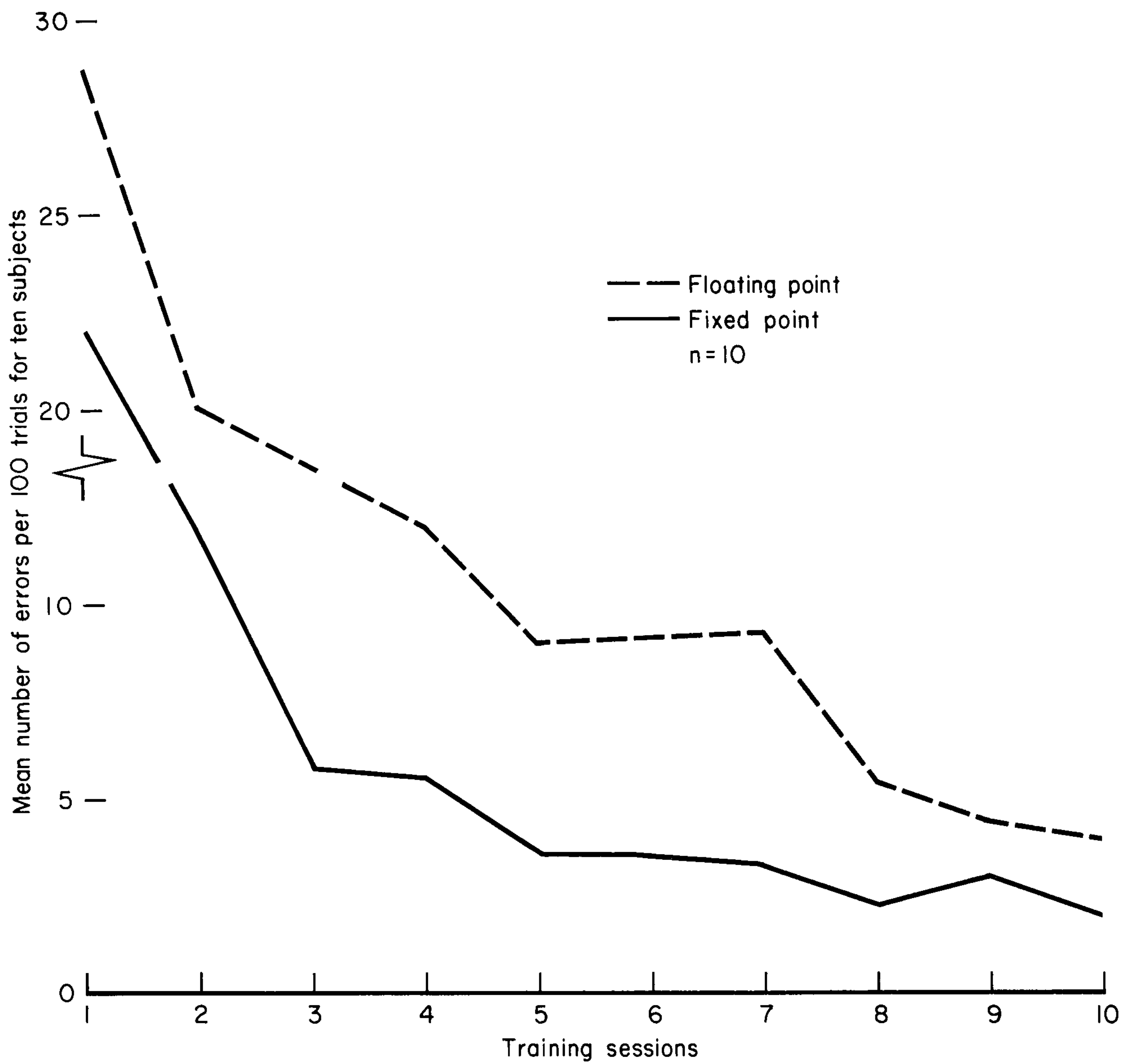

Figure 4.- Performance under "speed stress" condition.

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